FLEXIBLE TIMING CROSS-CALIBRATION WITH THE CRAB PULSAR

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A Simple, Flexible Method for Timing Cross-calibration of Space Missions

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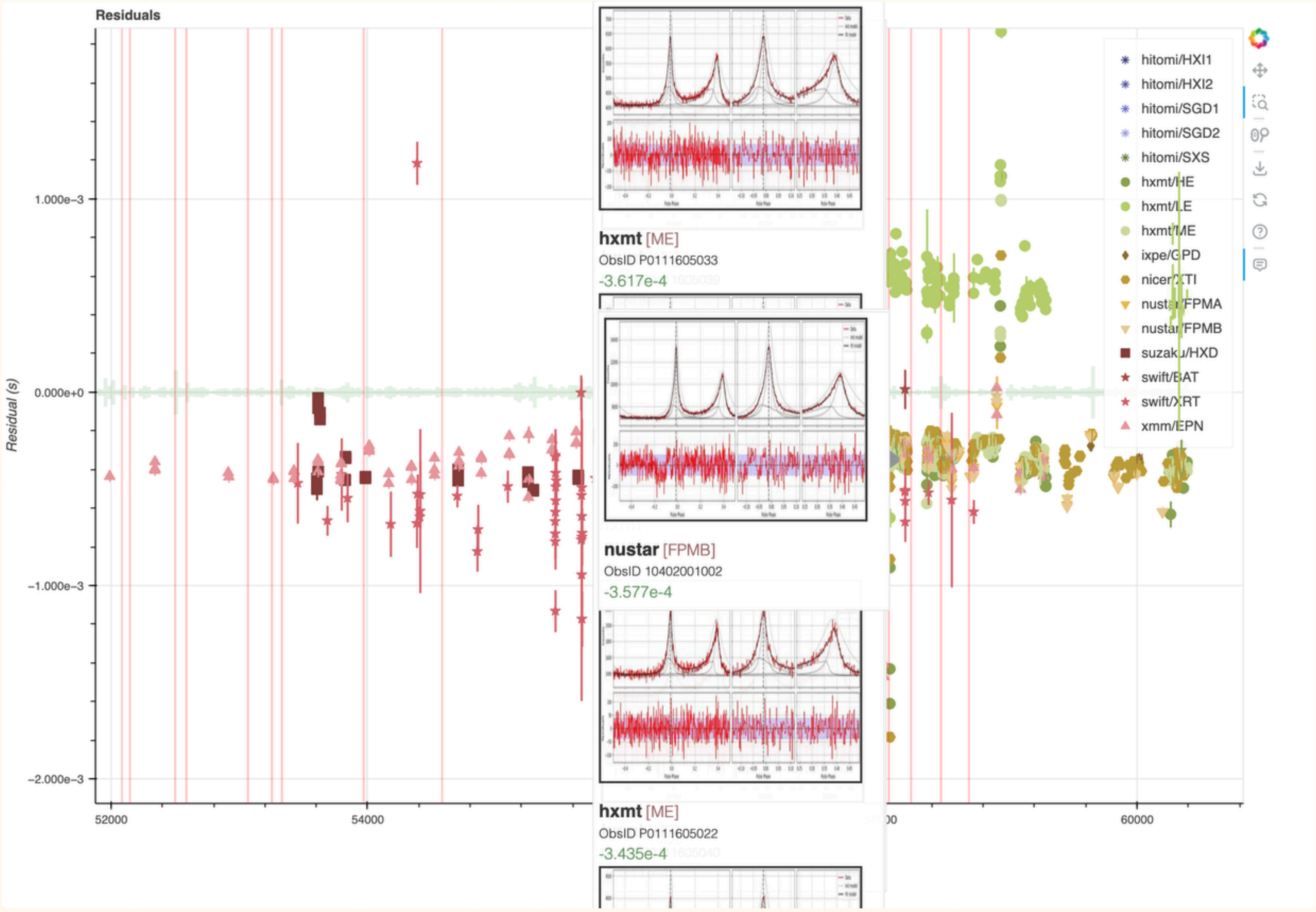
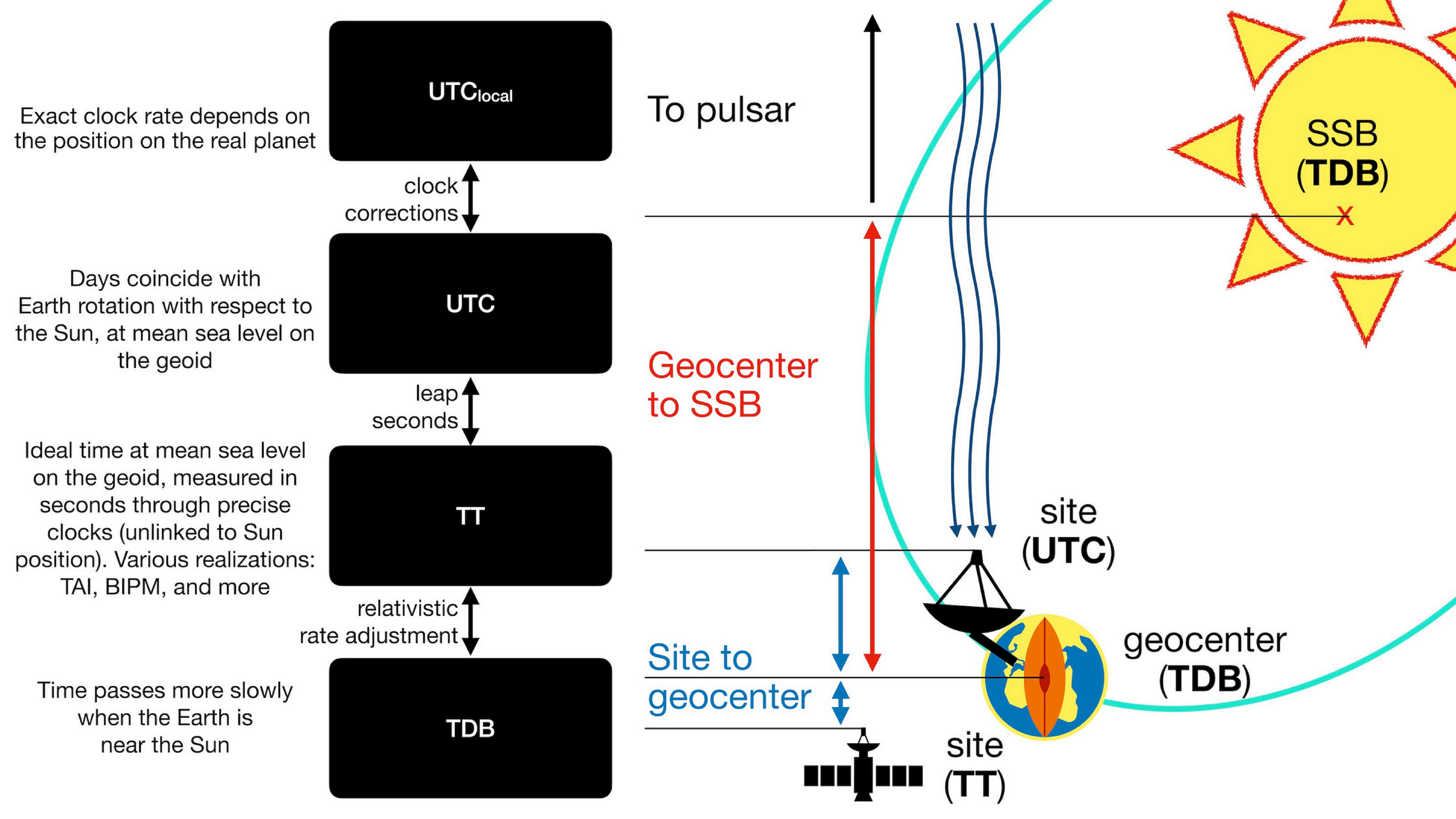
AIMS

Creating an automatic web-based browsable interface that tracks the timing calibration of all missions using the Crab (+ other pulsars)
Using a single code, one can avoid the subtle differences that can be introduced by independent processing

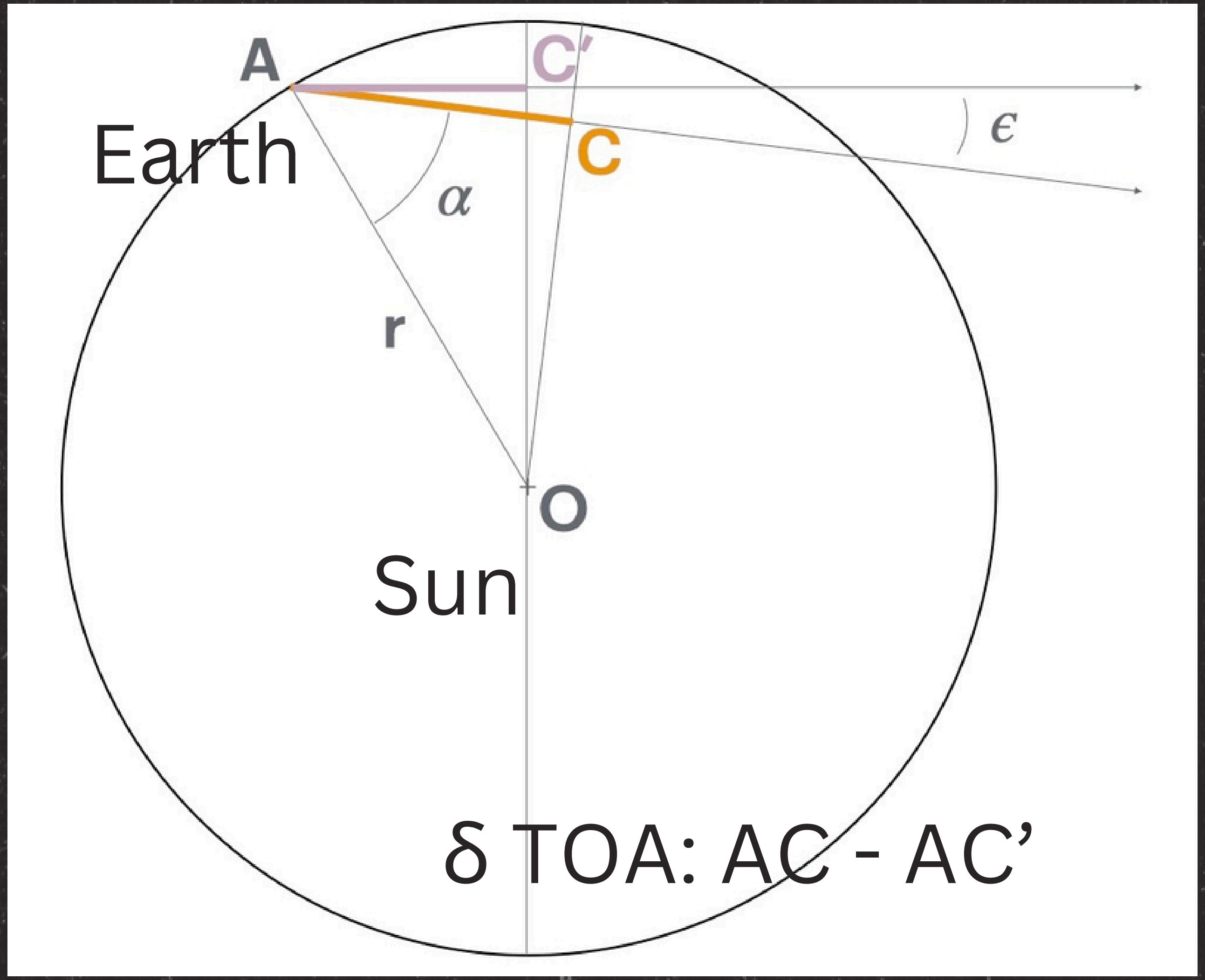
WHY the Crab?
Bright, constantly monitored. Used for the calibration of most missions already!

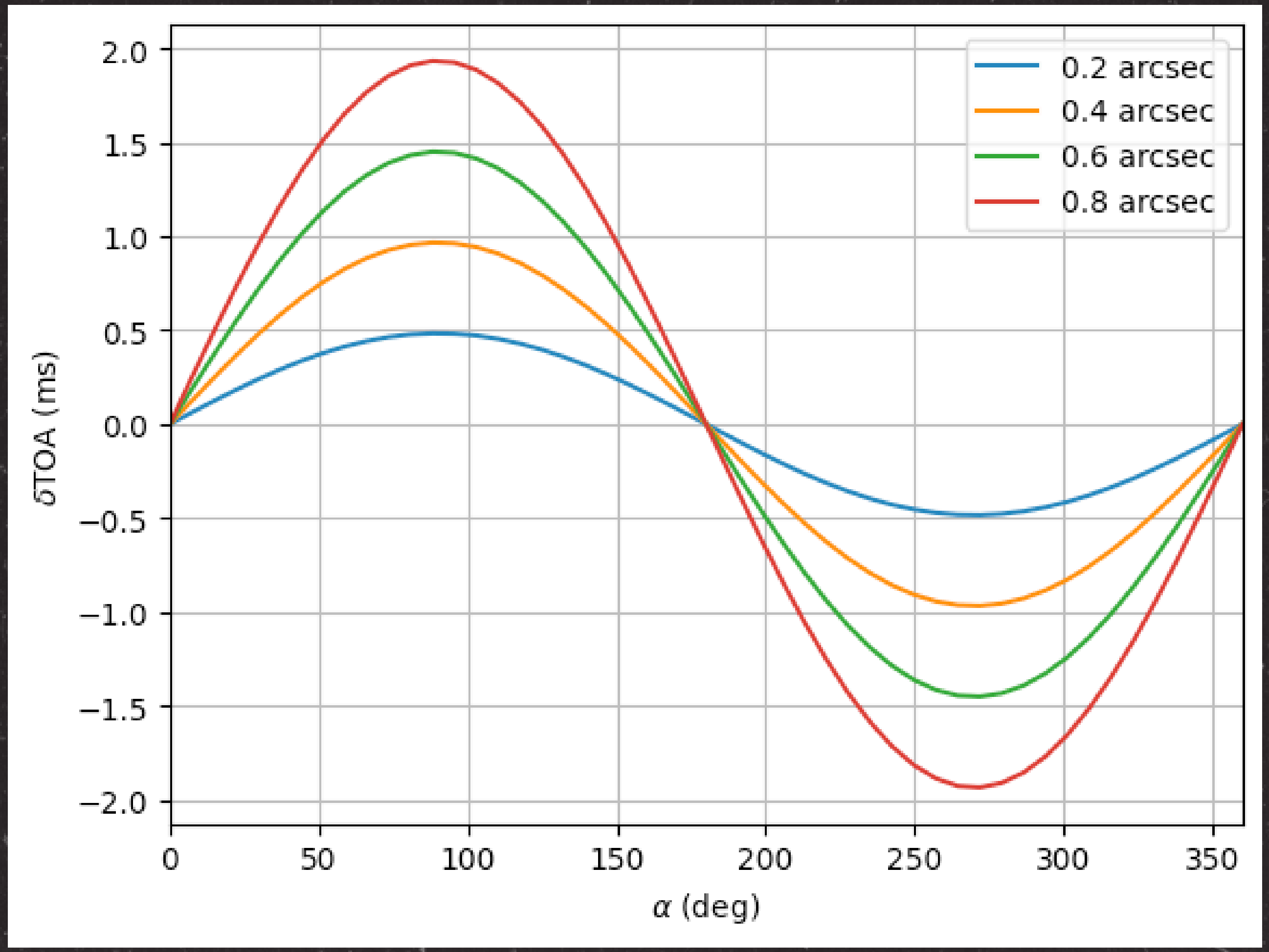



Exact clock rate depends on the position on the real planet
UTClocal
clock corrections
Days coincide with Earth rotation with respect to the Sun, at mean sea level on the geoid
UTC
leap seconds
Ideal time at mean sea level on the geoid, measured in seconds through precise clocks (unlinked to Sun position). Various realizations: TAI, BIPM, and more
TT
relativistic rate adjustment
Time passes more slowly when the Earth is near the Sun
TDB
To pulsar
Geocenter to SSB
Site to geocenter
SSB (TDB)
site (UTC)
geocenter (TDB)
site (TT)

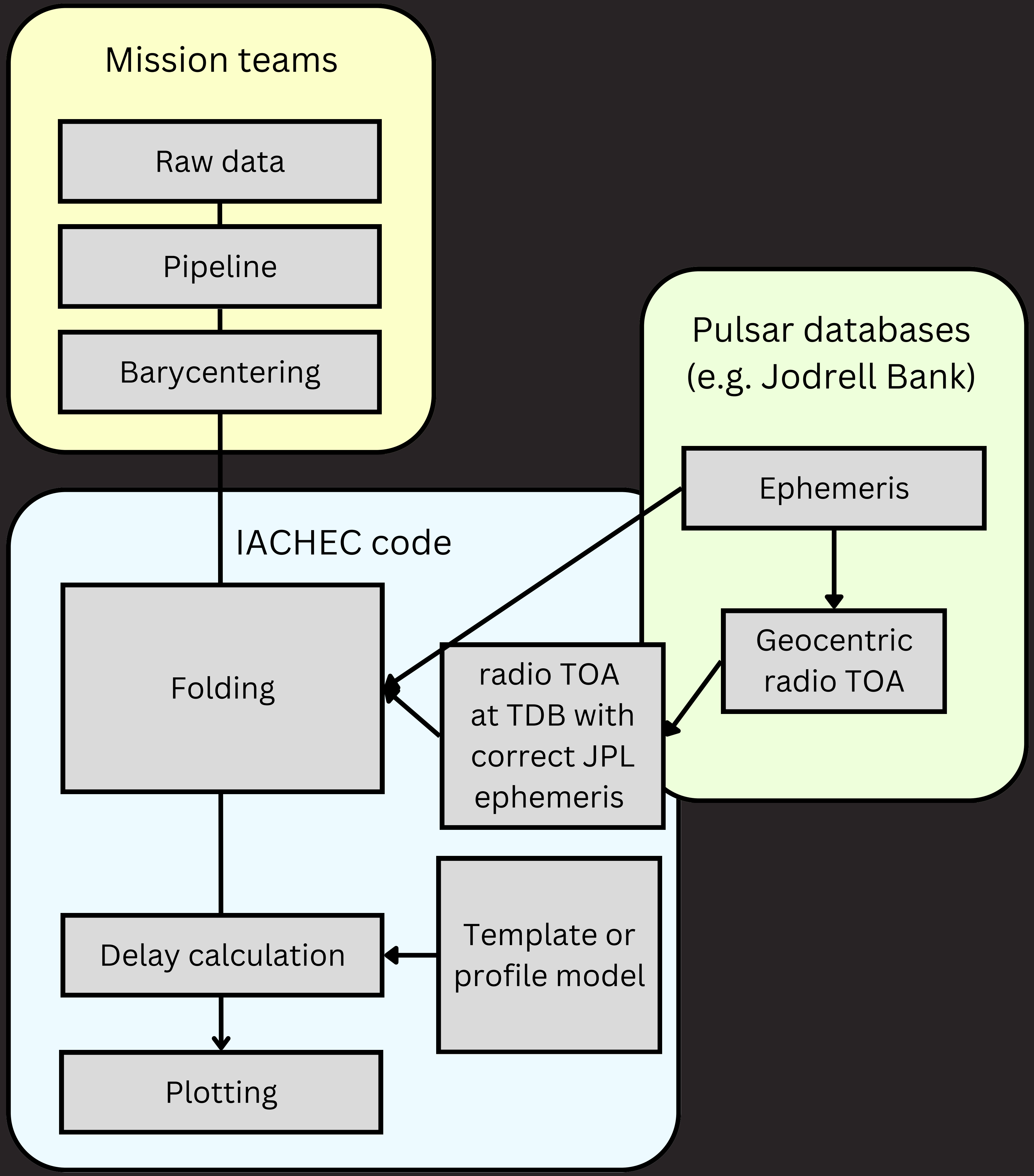
EPHEMERIS ISSUES

Using different JPL ephemerides and/or source positions can lead to TOA shifts by milliseconds.
Usual requirement: use the same JPL ephemeris and the same exact source position for everything, ignore proper motion. BAD and unfeasible.





TOA Extractor



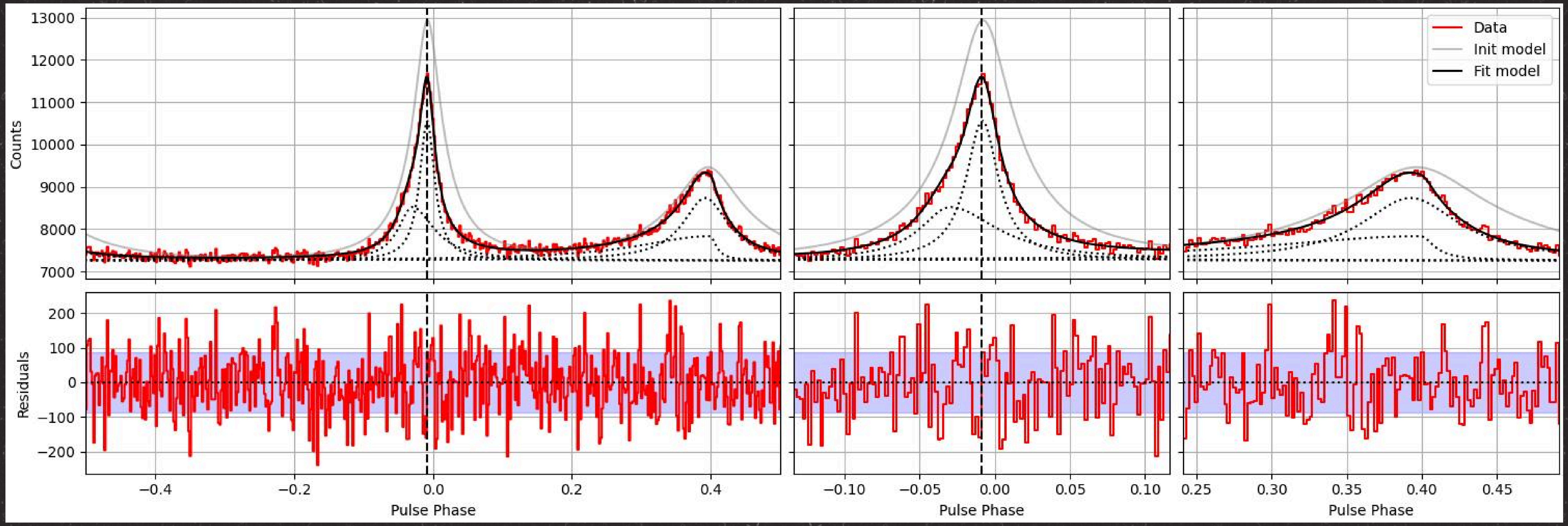
HOW THE CODE WORKS

Mission teams provide **barycentered** data, with the agreed ephemeris and source position. Pulsar databases provide the spin (and orbit when relevant) **parameters** and **TOAs.**

TOA CALCULATION

Two peaks, each as combination of symmetric Lorentzian + asymmetric Lorentzian

Gives numbers for each peak, uniquely identifies peaks, more flexible, only less rigorous in ideal case.



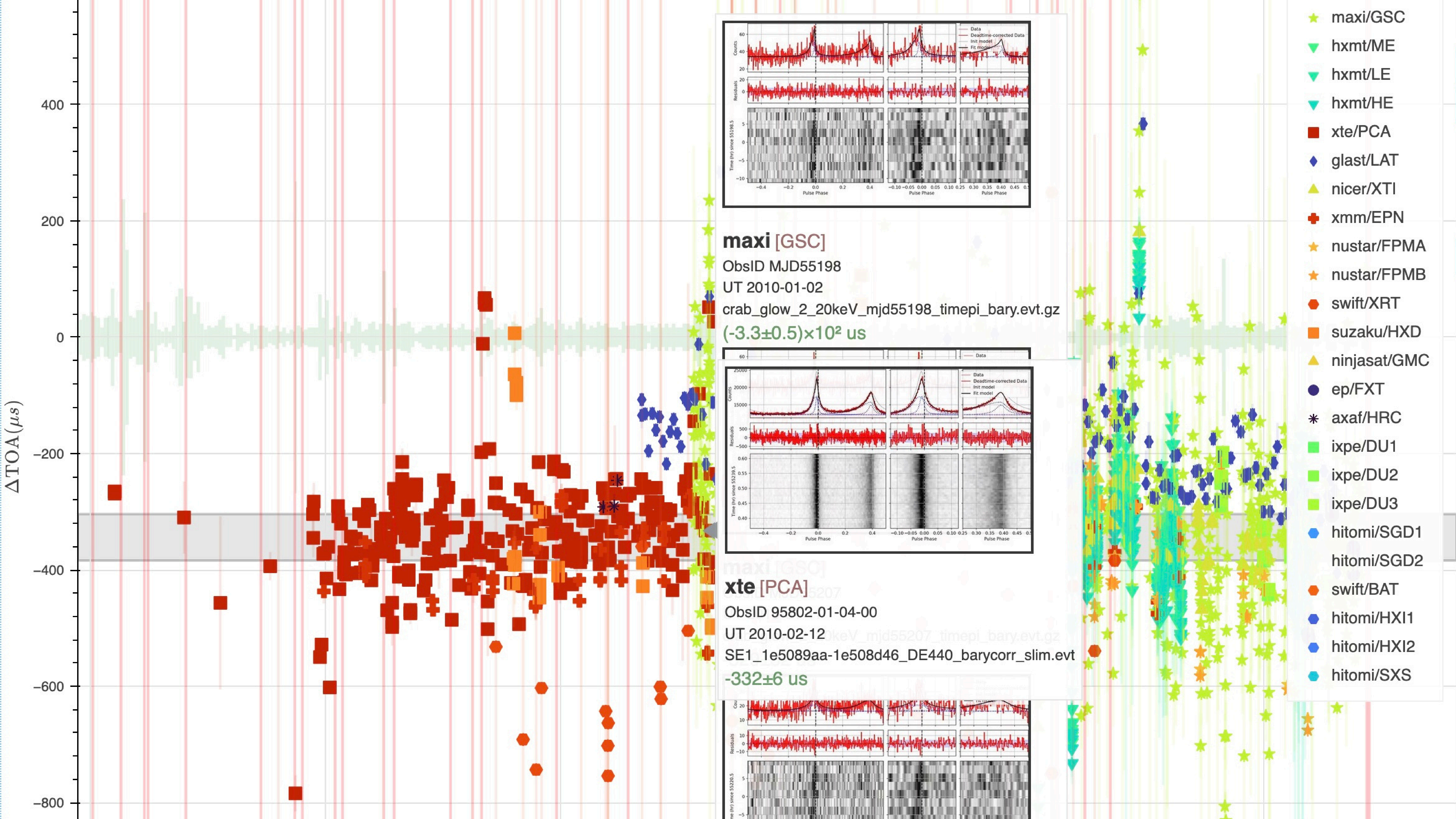

ΔTOA(μs)
400
200
0
−200
−400
−600
−800
maxi [GSC]
ObsID MJD55198
UT 2010-01-02
crab_glow_2_20keV_mjd55198_timepi_bary.evt.gz
(-3.3±0.5)×10² us
xte [PCA]
ObsID 95802-01-04-00
UT 2010-02-12
SE1_1e5089aa-1e508d46_DE440_barycorr_slim.evt
-332±6 us
Pulse Phase
maxi/GSC
hxmt/ME
hxmt/LE
hxmt/HE
xte/PCA
glast/LAT
nicer/XTI
xmm/EPN
nustar/FPMA
nustar/FPMB
swift/XRT
suzaku/HXD
ninjasat/GMC
ep/FXT
axaf/HRC
ixpe/DU1
ixpe/DU2
ixpe/DU3
hitomi/SGD1
hitomi/SGD2
swift/BAT
hitomi/HXI1
hitomi/HXI2
hitomi/SXS

Table 2
Summary of the Results in This Work, Separated by Mission and Instrument

Mission	Instrument	Min MJD	Max MJD	N	r_{mean} (μs)	σ (μs)	σ_{stat} (μs)	Rate (Counts s^{-1})	Pulsed Fraction (%)
AXAF/Chandra/CXO	HRC	51574.28	56589.14	11	−458	310	83	2.42	100
EP	FXT	60368.38	60758.73	7	−391	79	15	1490	34
GLAST/Fermi	LAT	54696.08	60617.92	196	−167	80	14	0.00498	84
HITOMI	HXI1	57472.63	57472.75	2	−264	⋯	27	73.1	61
HITOMI	HXI2	57472.63	57472.74	2	−214	⋯	63	68.6	57
HITOMI	SGD1	57472.63	57472.63	1	−244	⋯	78	1.17	52
HITOMI	SGD2	57472.63	57472.63	1	−157	⋯	690	0.217	50
HITOMI	SXS	57472.64	57472.64	1	−106	⋯	16	126	46
HXMT	HE	57992.43	60398.80	342	−370	90	12	1360	36
HXMT	LE	57992.60	60398.96	385	−319[a]	100	61	1220	38
HXMT	ME	57992.26	60398.95	518	−332	86	18	439	37
IXPE	DU1	59632.22	60727.75	7	−350	81	7.6	2.81	77
IXPE	DU2	59632.22	60727.75	7	−352	76	8.5	2.5	75
IXPE	DU3	59632.22	60727.75	7	−345	80	7.7	2.45	76
MAXI	GSC	55135.51	60866.50	3847	−312	200	120	0.42	49
NICER	XTI	57970.82	60364.52	145	−314	90	7	10400	38
NINJASAT	GMC	60365.09	60771.04	14	−406	53	22	26	44
NUSTAR	FPMA	56132.26	60388.08	79	−328	79	12	417	50
NUSTAR	FPMB	56132.26	60388.08	78	−329	76	14	394	49
SUZAKU	HXD	53604.23	56722.55	18	−326	170	310	53	39
SWIFT	BAT	57431.04	58190.06	3	20.5	160	58	6770	6.7
SWIFT	XRT	53454.21	58725.60	43	−615	150	1200	644	21
XMM	EPN	51632.96	59269.92	97	−356	90	15	178	42
XRISM	RESOLVE	60388.50	60388.50	1	−312	⋯	15	38.3	36
XTE	PCA	50205.36	55927.00	312	−333	74	6.1	10600	46

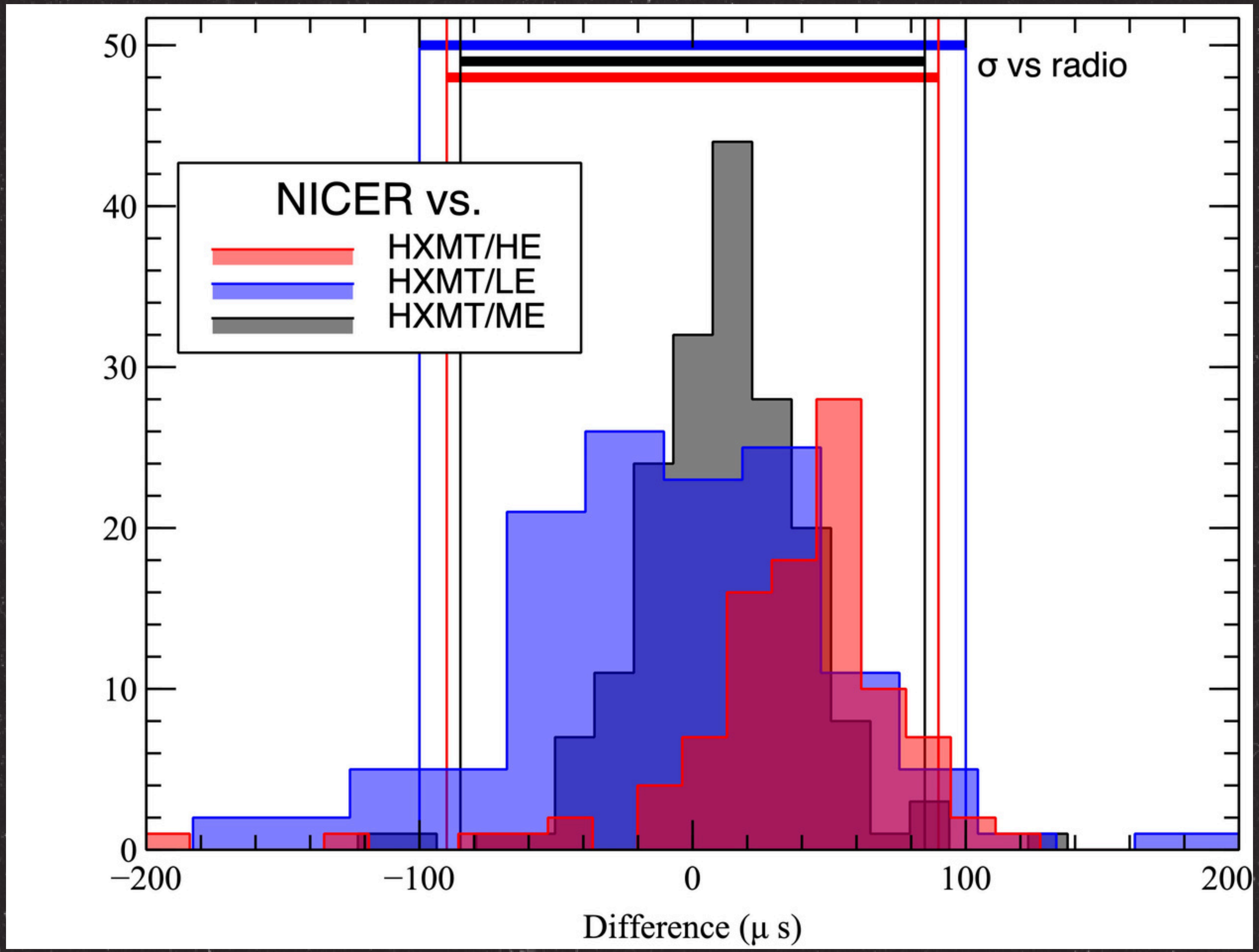
Notes. The mean residuals r_{mean} are calculated as the median (if $N > 20$) or the average of the residuals of the X-ray TOAs with respect to the radio TOAs; the standard deviation σ similarly uses the median absolute deviation and the standard deviation in the two cases. For missions with too few observations we do not report the standard deviation. σ_{stat} is the median/mean statistical error on the single TOA measurement. Some long observations, or observations from high-throughput instruments, had sufficient counts to allow multiple TOAs. Missions with >1000 observations are not completely analyzed, the table shows the status at 2025 September 02.

[a] We applied a known offset of -864 μs to the measured value (Tuo et al. 2022).

CROSS CHECKS

This wealth of data allows for cross checks between instruments.

More precise than X-ray vs radio!



Type People Modified

Name	Owner	Last m...	File size
raw_data	me	May 12, 2022	—
IXPE	me	Apr 30, 2022	—
XRT	me	Nov 9, 2021	—
HXMT	me	Oct 20, 2021	—
NICER	cphu0821@g...	May 13, 2021	—
BAT	me	May 3, 2021	—
Suzaku	yukikatsu.ter...	Apr 27, 2021	—
Hitomi	me	Apr 26, 2021	—
XMM	srosen@scio...	Apr 20, 2021	—
NuSTAR	me	Sep 15, 2020	—
README	me	3:51 PM	2 KB
Get Residuals.ipynb	me	3:15 PM	250 KB

matteobachetti / TOAextractor

Code | Issues 2 | Pull requests | Actions | Projects | Wiki | Security | Insights | Settings

TOAextractor Public

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main | 2 Branches | 14 Tags | Go to file | Add file | Code

matteobachetti Merge pull request #22 from matteobachetti/fix_very_long... 54911a4 · 1 minute ago 181 Commits

.github/workflows	Make windows test experimental	11 months ago
docs	First draft	4 years ago
licenses	First draft	4 years ago
toa_extractor	Fix syntax	20 minutes ago
.gitignore	First draft	4 years ago
.readthedocs.yml	First draft	4 years ago
MANIFEST.in	First draft	4 years ago
README.rst	First draft	4 years ago
pyproject.toml	First draft	4 years ago
setup.cfg	Update dependencies; fix issue with recent Bokeh	10 months ago
setup.py	First draft	4 years ago

About

A pipeline to extract TOAs from X-ray observations of the Crab pulsar and others. Mostly for cross-calibration purposes

Readme
Activity
2 stars
1 watching
1 fork

Releases 11

Release v0.3.3 Latest
on Jul 20, 2024

+ 10 releases

Packages

No packages published
Publish your first package

RESOURCES

TOA calculation code:
https://github.com/matteobachetti/TOAextractor

Deadtime correction code:
https://github.com/matteobachetti/pulse_deadtime_fix

What next?

More missions

Add AAAALLLL missions to the archive

More pulsars

AAAAAALLLL the pulsars!

Web app

Current system based on Google Colab works, but can be improved

Crab science

Systematic study of Crab pulse profile at different energies, and possible radio/X delays (extend previous work by IACHEC members)